A modular software framework for test-beam data analysis

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T5 - Software development

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Motivation | physics and prototype sensors

• Understanding the impact of radiation damage on the detector performance:
  ✓ Charge collection
  ✓ Position resolution
  ✓ Efficiency

• Sensor configuration
  ✓ Sensor types (thicknesses, doping profiles, implant widths)
  ✓ Inter-pixel isolation
  ✓ Edge designs

• Detailed studies with particle beam are essential for proper evaluation of detector prototypes
  ✓ After characterisation and calibration in the lab, the sensors need to be tested using high intensity particle fields, that are able to provide quickly high fluences up to $10^{16}$ [1 MeV n$_{eq}$/cm$^2$]
  ✓ Uniformly and non-uniformly irradiation schemes
• A dedicated high resolution pixel telescopes are being developed at different sites:

✔ 180 GeV beam of protons and pions provided by the SPS at CERN

✔ **Timepix3 telescope** - reconstructs the position and time information for the particles traversing the pixel sensor
The data produced by the telescope can be synchronised with the information from the DUT (device under test)

✓ The LHCb software embedded in the Kepler project performs the decoding of raw data and produces track objects inside the official LHCb's Gaudi framework.

✓ What next?
The data produced by the telescope can be synchronised with the information from the DUT (device under test)

The LHCb software embedded in the Kepler project performs and produces track objects inside the official LHCb's Gaudi framework.

Prototyping and testing of new materials and sensor designs is cumbersome and time consuming. Having a comprehensive software platform to handle various test beam data sets is essential for efficient data analysis.

What next?
Tb Analysis | General workflow

Data
- Experiment processed

⇒ Ntuples (e.g. Clusters & Tracks)

s/w

- Common data type for Tb analyses: .root files prepared under exact configuration
- Shared Tb data to be analysed (e.g. EOS area)
- All Tb analysers use same preprocessed data

Plots
- Easy compilable and reproducible Tb results
- Series of control plots
- Systematics

Pros and cons
+ Easy to combine series of Tb measurements
+ Produce plots in the same style
+ Repeat a selected analysis (e.g., new DUT, new data sample or just a cross-check)
+ Different analyses added as plugin tools, e.g. elliptical binning (motivated by different irradiation schemes)

- Two stages of data processing - need to pre-process data in test-beam facility s/w
The **TbGaudi** framework

- **General** or experiment specific...
- **C++**, python, ...
- Modular...
- User friendly...
- **Easy to adapt** by any group that is working on new sensor technology.

**TbGaudi**
- Data (Ntuples) Svc
- Binning schemes
- Irradiation schemes
- Fitting dataset handler
- TbAnalysis abstract interface
- ...

**TbExpAnalysis** inherits from **TbGaudi::TbAnalysis**
- Data and Tb conditions
- Fitters definitions
- Irradiation scheme conditions (eg. beam allignment)
- Results combination

- **TbVeloPixAnalysis**
- **TbUTAnalysis**
- Other requests ? ;)

s/w
The TbGaudi framework | user analysis code

**TbVeloPixAnalysis**

```cpp
#include "main.h"

int main(int argc, char ++argv)
{
    TbStyle::Style(tbStyle::LHCb);
    auto MyAnalysis = new TbVeloPixAnalysis{};
    MyAnalysis->CCE_IRRAD();
    // any other analysis method
    PressEnterToQuit();
    return 0;
}
```

```
RunNumber TTree Dut Vendor BiasVoltage [V] NominalAngle [deg] Irkum [nA] Temprature [celsius]
12053 Clusters S8 HPK 160 0 0 0
12047 Clusters S8 HPK 380 0 0 0
12050 Clusters S8 HPK 200 0 0 0
12044 Clusters S8 HPK 480 0 0 0
12041 Clusters S8 HPK 580 0 0 0
12038 Clusters S8 HPK 680 0 0 0
12035 Clusters S8 HPK 780 0 0 0
12032 Clusters S8 HPK 880 0 0 0
12028 Clusters S8 HPK 980 0 0 0
12024 Clusters S8 HPK 1080 0 0 0
```
The TbGaudi framework | user analysis code

TbVeloPixAnalysis

```cpp
#include "TbVeloPixAnalysis.h"

void TbVeloPixAnalysis::CCE_IRRAD()
{
  std::cout << "[INFO]: TbVeloPixAnalysis::CCE_IRRAD is executed... " << std::endl;

  // *** DEFINE BASIC LOCATIONS ***
  TbGaudi::TB_DATA_LOCATION("/eos/lhcb/user/b/brachwal/DATA/Upgrade/testbeam/velo/CCE/");
  TbGaudi::TB_RUN_DB_LOCATION("/afs/cern.ch/work/b/brachwal/SoftDev/Tb/TbVeloPix/data");
  TbGaudi::TB_RUN_DB_FILE("DutTBODExample.dat");

  // *** DEFINE ANALYSIS REQUIREMENTS ***
  TbAnalysis::ClustersSize(1);
  TbAnalysis::ReduceHotPixels(true);
  TbAnalysis::DutBinningType("Elliptic");
  TbAnalysis::FluenceMapping(true); // requires experiment specific methods implementation

  // *** LOAD DATA ***
  ReadTbData(12044); // S8 HPK -300V
  ReadTbData(12038); // S8 HPK -600V

  // *** RUN ANALYSIS ***
  MPVMapMaker();

  // *** PLOT / COMBAIN RESULTS ***
  Plot("MPV_2DMap"); // for each defined TbRun
  Plot("MPV_ProfileX"); // for each defined TbRun
  Plot("MPV_ProfileY"); // for each defined TbRun
  Plot("MPV_Fluence",12044); // for a single TbRun
  Plot("MPV_Fluence",-1); // for all defined TbRuns
```
Diff. radiation schemes are followed by adaptive binning – benefit for statistic and physics analysis (easier to interpret results)

* The IRRAD proton facility is located on the T8 beam-line at the CERN PS East Hall
 Deposited energy fitting

- Charge distribution is far from *simple* Landau description,
- Basic/generic fitters are defined within TbGaudi (Landau + Gauss convolution),
- However, the fitter can be extended by a given TbExpAnalysis implementation, e.g. taking into account background/noise modeling.

LHCb VeloPix Preliminary
Most Probable Value maps
Analysis curves

- It's really hard to *compile series of different DUT analyses* without a *framework*.
- It's would be really easy to re-run the whole analysis – if needed.

This is related to the *data preservation*. 
1. Series of test beam R&D studies are being performed by different groups/experiments;

2. By this presentation the TbGaudi (a modular software framework based mostly on ROOT) has been proposed for test-beam data analysis;

3. It’s an easy to adapt framework by any group that is working on new sensor technology.